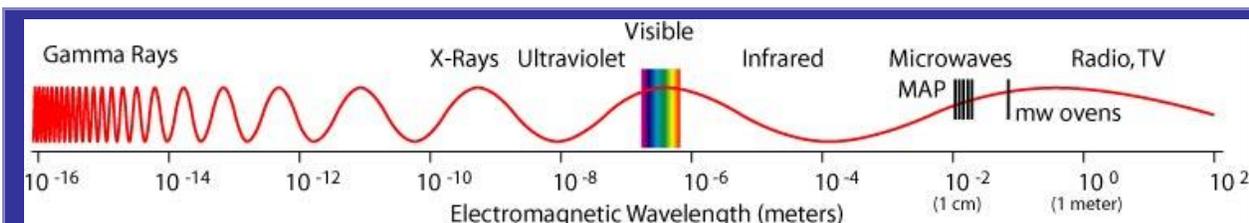




## More Discoveries... Better Descriptions

From the 1890s through the 1930s, asteroid research was buzzing with excitement; a total of 1140 asteroid discoveries occurred during this time. With such a surge in activity, it became necessary to record and communicate the latest findings. Beginning in the 1890s, this responsibility was fulfilled by the Rechen-Institut in Berlin. They kept track of asteroids, published predictions of asteroid positions and the *RI Circulars*, which contained updated information about asteroids. During the early 1930s, the rate of asteroid discovery averaged about 38 per year. At the same time, new photographic (see “Silver to the Rescue”) and **spectroscopic** (see “[Dawn Dictionary](#)”) technologies merged with telescopes to determine asteroids’ shapes and the elements in their atmospheres. By 1929, **Nicholas Bobrovnikov** had used these newly-developed technologies to determine the **spectra** of twelve asteroids. He found that Ceres was bluer than Vesta, indicating that Ceres was reflecting more high-energy radiation than Vesta.



*Spectroscopes break up visible light into a spectrum of different wavelengths so that the light energy can be analyzed. Notice in the illustration above, visible light accounts for a small part of the electromagnetic spectrum. Consider this in the historical context of asteroid research: imagine how much more is out there than meets the eye!*

<http://faculty.mwc.edu/tmichalik/electromagspec.htm>

By 1939, asteroid discoveries and studies came to a screeching halt. Why? Think about world history. What was going on in Europe during the late 1930s through the 1940s? With the beginning of World War II in 1939, asteroid research virtually ended for almost three decades because the world’s attention and resources were directed to the war effort. However, as you will see, some of the technologies developed during World War II yielded beneficial applications in astronomy.

### Asteroid Research in the Post-World War II Era

After World War II, the activities of the Rechen-Institut were scattered. Parts of the material were moved to Heidelberg, but at least half of it remained in Soviet-controlled Berlin. The German observatories that had undertaken asteroid work before the war lacked essentials like photographic plates to continue their work. When the International Astronomical Union (IAU) met in Copenhagen, Denmark in 1946, it assigned most of the activities that had been centered in Germany to Soviet astronomers and observatories.

The Minor Planet Center in Cincinnati, Ohio was established as the IAU center for asteroid research in 1947. Since asteroid programs had become so disorganized during the war, the primary efforts of the center were focused on keeping track of the almost 1,600 known asteroids. Other activities of the center, under the direction of **Paul Herget**, included publishing *Minor Planet Circulars*, collecting and maintaining asteroid observations, and calculating asteroid orbits and their positions. Eventually the Center was transferred to Cambridge, Massachusetts.

Another astronomer studying asteroids during the post-war period was Netherlands-born **Gerard Kuiper**, who worked in the McDonald Observatory in Texas. From 1950 to 1952, he conducted an asteroid survey using a 10-inch telescope that recorded asteroids down to a **magnitude** of 16.5 and photographed the entire **ecliptic** twice. This technique produced a clearer picture of asteroid distribution in space and provided statistical data on asteroid population. In 1960, **Tom Gehrels** was involved with the Palomar-Leiden Survey, observing smaller areas of the sky and making brightness and distance measurements of some 1,800 asteroids. In 1971, Gehrels edited the first text on asteroids and organized the first asteroid conference in Tucson, Arizona.

### More Accurate Brightness Measurements

Whereas 19<sup>th</sup>-century astronomers could measure an asteroid's **brightness** to an accuracy of 0.1 of a magnitude, new **photographic** technologies (see "Silver to the Rescue") improved the accuracy of measurements to about 0.05 of a magnitude. The advent of the RCA **photomultiplier tube** during World War II was first used in astronomy in the early 1950's in a process known as **differential photometry**. Three measurements, using ultraviolet (U), blue (B), and visual (V) filters, were integrated in minutes with an accuracy of 0.001 magnitude. This UB<sub>V</sub> system became the standard method for measuring brightness.

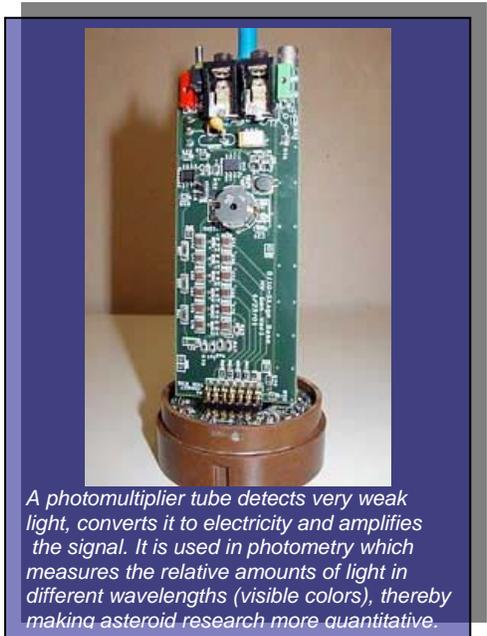
### Rotation Rates from Light Curves

The introduction of computers, which corrected for air mass and subtracted background sky brightness, decreased the time necessary to process the data from the UB<sub>V</sub> observations, and made it possible to measure asteroid **rotation rates** from their **light curves** (see "Vegetable Light Curves"). Astronomers had attempted to detect asteroid light variations as early as 1810, but small variations (some as small as a few hundredths of a magnitude), erratic curves resulting from irregular shapes, and varying numbers of brightness peaks during each rotation made meaningful measurements difficult until the late 1960s.

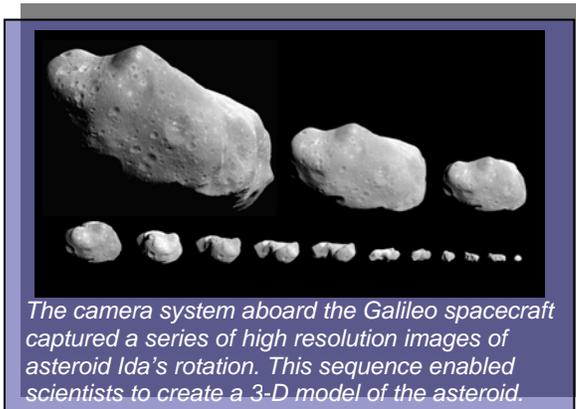
### Asteroid Shapes Based on Light Curves

Starting in 1971, astronomers tried a number of methods for modeling asteroid shapes based on their light curves. Modeling techniques included rotating Styrofoam bodies covered with substances such as powdered rock and graphite. Another procedure known as the **convex-profile inversion** produced a two-dimensional convex profile, which was then used to produce a three-dimensional shape.

A new technology, **speckle interferometry**, was developed in the mid-1970s. SI uses ground-based telescopes and computer technology to make highly detailed or high-resolution images of asteroids by clustering together loads of tiny "specks" to form a clearer picture. These large telescopes capture a series of rapid exposures lasting only a few thousandths of a second. If you had a camera with a



<http://www.siac.stanford.edu/quarknet/Workshop2003/CosmicRayDetector/>



<http://photojournal.jpl.nasa.gov/catalog/PIA00070>

shutter speed that fast, you would never have to worry about somebody blinking or developing a blurry picture simply because somebody moved. This super-fast freeze frame also makes it possible to eliminate the blurry effects of a constantly moving atmosphere. Therefore, when a series of frames, taken over several minutes, are combined into a single image by a computer, the result is a clearer picture of an asteroid's shape. Based on such observational data and theoretical calculations, the shapes of 1 Ceres and 2 Pallas were determined to be nearly spherical, and 3 Juno and 4 Vesta were found to be elliptical.

## The Rest of the Story

In 1987, speckle interferometry revealed some surprising information. It showed that 4 Vesta is **dimmiest** when its maximum cross section faces Earth, and that its surface features have more influence on its light curve than does its shape. If you have done the Vegetable Light Curve activity, you learned that the surface area directly affected the light curve. The larger the exposed surface area, the more light was reflected, so the brighter the object appeared. This 1987 finding about Vesta appears to contradict the Vegetable Light Curve activity. Instead it shows that variations of brightness in an asteroid's light curve involve not only the amount of surface area being observed, but also the **albedo** of irregularities and craters on an asteroid's surface.

In the 1980s, new electronic techniques employing **charge-coupled devices (CCDs)** had an enormous impact on asteroid research. CCDs combined with computer data processing provide astronomers with greatly enhanced observational capabilities. For example, the Spacewatch Program used CCDs in the discovery of a near-earth asteroid in 1989. This Arizona-based program, which has as a general goal of discovering small objects in the solar system, has identified numerous new asteroids smaller than 100 meters in diameter using CCD technology. CCD equipment is now available to amateur astronomers who have been finding comets and asteroids for years. Other successful professional electronic discovery programs are now located in New Mexico, Hawaii, and other parts of the world.



CCDs are electronic detectors placed in telescopes. The CCD shown here is packed with hundreds of tiny light-sensing diodes, each of which records the brightness of light and transmits this data to a computer.

<http://fuse.pha.jhu.edu/~wpb/spectroscopy/measure.html>



The Hubble Space Telescope in orbit.

<http://hubblesite.org/gallery/showcase-original/telescope/t3.shtml>

Observations by the ground-based Keck II Telescope in Hawaii, the **Hubble Space Telescope**, and unmanned spacecraft (see "I Can See You More Clearly Now" and "Modern Era of Asteroid Study") are now contributing new knowledge about asteroids' shapes, rotation rates, and surface features. The Dawn mission's technology will allow us to "travel back in time" over 4.5 billion years. By focusing on the internal structure, density, magnetization, elemental and mineral composition of Vesta and Ceres, scientists will gather evidence to shed some light on the mysteries of our solar system's origins.

## Additional Resources

### Web Sites

<http://cfao.ucolick.org/>

The Center for Adaptive Optics includes information and images about the latest technology for improving visual images obtained from various optical instruments including astronomical telescopes.

<http://cobalt.golden.net/~kwastro/Stellar%20Magnitude%20System.htm>

This article "The Stellar Magnitude System," originally published in *Sky & Telescope* magazine, explains how magnitude has been measured throughout history, and shows how the measurement system changed in response to new technologies.

<http://www-ssc.igpp.ucla.edu/dawn/index.html>

<http://dawn.jpl.nasa.gov/>

Learn more about NASA's Dawn mission by visiting the above listed Web sites.

<http://imagine.gsfc.nasa.gov/docs/introduction/emspectrum.html>

This NASA Web site offers helpful texts about the electromagnetic spectrum. Featured topics include: *Measuring the Electromagnetic Spectrum*, *Why Do We Have to Go to Space to See All of the Electromagnetic Spectrum?*, *Space Observatories in Different Regions of the EM Spectrum*, and more.

<http://neo.jpl.nasa.gov/images/vesta.html>

Hubble Space Telescope and Keck images of Vesta

<http://nssdc.gsfc.nasa.gov/planetary/factsheet/asteroidfact.html>

Asteroid Fact Sheet

<http://seds.lpl.arizona.edu/nineplanets/nineplanets/asteroids.html>

Historical information on asteroid discovery, data and images of specific asteroids.

<http://www.exploratorium.edu/snacks/spectra.html>

Provides instructions for a hands-on activity to build your own spectroscope out of a shoebox.

<http://www.solarviews.com/cap/ast/vesta.htm>

Animation of Vesta rotation

### Print Resources

McSween, H.Y. (1999). *Meteorites and their parent planets*. Cambridge; NY: Cambridge University Press.

Peebles, C. (2000). *Asteroids: A history*. Washington, DC: Smithsonian Institution Press.

Roth, G.D., (1962). *The system of minor planet*. Princeton, NJ: Company Inc.